Active Rectifiers

- Op amps can be used with diodes to create better properties.
- Real diodes have a forward “diode drop” and small reverse current.

\[
V_A - V_B \quad I = I_S(e^{\Delta V/V_T} - 1)
\]

\[
V_D \approx 0.6V \quad I
\]
**Ideal Diode**

- The simple rectifier uses a diode to short signals

\[
\frac{v_{\text{in}}}{\text{diode}} \rightarrow \frac{v_{\text{out}}}{\text{diode}}
\]

- This cannot rectify signals less than 0.6 V.
- Feedback can be used to make an “ideal” diode.

\[
\begin{align*}
\text{If } v_{\text{in}} &> 0, \quad v_{\text{out}} = v_+ = v_- = v_{\text{in}}, \quad v_a = v_{\text{in}} + 0.6 \text{ V.} \\
\text{If } v_{\text{in}} &< 0, \quad v_a < 0, \quad \text{the diode is non-conducting and } v_{\text{out}} = 0 \text{ V.}
\end{align*}
\]

- This circuit is slew rate limited, for negative signals it goes to \(-V_{EE}\).
Faster Rectifier

- The op-amp can be protected from going to $-V_{EE}$.

- If $v_{in} < 0$, $v_{out} = -v_{in}$, $v_a = v_{out} + 0.6$ V, $D_2$ is conducting.
- If $v_{in} > 0$, $v_a < 0$, $D_1$ is conducting, $v_a = v_{in} - 0.6$ V, $v_{out} = 0$.
- As $v_{in}$ goes from negative to positive, $v_a$ goes from +0.6 to -0.6 V.

- This is faster than going from -15 V to +0.6 V for the same slew rate.
Two Stage Rectifier

- Add a x1 inverter before this circuit to make a conventional rectifier that passes positive signals only.

The first amplifier stage provides a -1 inverter with 100 kΩ input impedance.

The second amplifier acts as a half wave rectifier.

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Active Full-wave Rectifier

- Two amplifiers can be used to make a full-wave rectifier.
- A switchable inverter/buffer can use an op-amp as the switch.

\[ \text{If } v_{\text{in}} < 0, v_{\text{cont}} = 0.6, \text{ and the circuit inverts.} \]
\[ \text{If } v_{\text{in}} > 0, \text{ the diode is non-conducting, so no feedback.} \]
Faster Full-Wave

- The fast half-wave rectifier can be used with an inverter.

- The first stage produces \( v_{\text{half}} \).

- The second amplifier is an inverting summation circuit with the upper line (\( v_{\text{in}} \)) summing at x1 and the lower line (\( v_{\text{half}} \)) summing at x2.

- The net effect of the second inverter is \( v_{\text{out}} = -(v_{\text{in}} - 2v_{\text{half}}) \).

- For \( v_{\text{in}} > 0 \), \( v_{\text{half}} = -v_{\text{in}}, \) \( v_{\text{out}} = v_{\text{in}}. \)

- For \( v_{\text{in}} < 0 \), \( v_{\text{half}} = 0, \) \( v_{\text{out}} = -v_{\text{in}}. \)
Peak Detector

- A diode and a capacitor can be used as a peak detector.

\[ v_{in} \quad D \quad i_D \quad v_{out} \quad C \quad i_C \]

\[ i_C = C \frac{dv_{out}}{dt} \]

- If \( v_{out} < v_{in} - 0.6 \text{ V} \), \( v_{out} = v_{in} - 0.6 \text{ V} \)
- If \( v_{out} > v_{in} - 0.6 \text{ V} \), \( i_C = 0 \), \( v_{out} = \text{const.} \)

- The voltage through the diode is stored on the capacitor.
- The voltage is stored as a charge \( V = Q/C \) until a higher value comes along.
- The diode drop matters; \( v_{in} - 0.6 \text{ V} \) is stored on the capacitor.
Active Peak Detector

- An active rectifier can be combined with a capacitor to store the true input voltage.

![Diagram of Active Peak Detector]

- The first amplifier is set up as an ideal diode.
- Positive voltage through the diode is stored at the capacitor. The response is limited by the slew rate and output current, $I_{max}$, of the first amplifier.

\[
\frac{dv_{out}}{dt} \bigg|_{max} = \frac{1}{Cd} \frac{dQ}{dt} = \frac{I_{max}}{C}
\]

- The second amplifier is a x1 buffer and the large input impedance (related to $I_B$) prevents the capacitor from draining too rapidly.

\[
\frac{dv_{out}}{dt} \bigg|_{droop} = \frac{I_B}{C}
\]